REPORT No. 700

PRELIMINARY INVESTIGATION OF THE FLYING QUALITIES OF AIRPLANES

By H. A. Soulé

SUMMARY

The National Advisory Committee for Aeronautics is undertaking an investigation of the flying qualities of airplanes. The work consists in the determination of the significant qualities susceptible of measurement, the development of the instruments required to make the measurements, and the accumulation of data on the flying qualities of existing airplanes, which data are to serve as a basis for quantitative specifications for the flying qualities of future designs.

A tentative schedule of measurable flying qualities has been prepared and the instruments needed for their measurement have been assembled. Two sets of instruments have been used: One set consists of special N. A. C. A. recording instruments and the other set consists of generally available commercial instruments including those usually found on the instrument panels of large airplanes. A trial of the schedule and the instruments has been made using the Stinson SR–8E airplane.

The results showed that, although the original schedule and instruments are basically satisfactory, some further development is required to eliminate nonessential items and to expedite flight testing. The report describes and discusses the work done with this airplane.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting an investigation of the flying qualities of airplanes. The work in connection with this investigation is divided into three phases that are proceeding simultaneously. The first phase consists in determining factors susceptible of measurement that can be used to define quantitatively the flying qualities of an airplane. The second phase consists in the development of instruments and test procedure for making the required measurements. The third phase consists in the accumulation of data on the flying qualities of existing airplanes to serve as a basis for the establishment of quantitative specifications for the flying qualities of future designs. These data will also be useful as a basis for any analysis that may be made regarding the particular points which are shown to be in need of improvement.

The first work of the investigation was done by E. P. Warner in an advisory capacity relative to the preparation of the specifications for the DC–4 airplane. He consulted a considerable number of air-line pilots, engineers connected with both the operating and the manufacturing companies, and research men, including members of the N. A. C. A. staff, in order to obtain the general ideas of the industry as to the flying qualities and the possible tests that could be made to determine them. The results of this survey, which were used in the preparation of the specifications for the flying qualities of the DC–4 airplane, were presented to the Committee with a request for its cooperation. The second phase of the work consisted in the consideration of the results of the survey by members of the N. A. C. A. staff and the preparation of a tentative schedule of flying qualities and of tests by which they could be determined. In the preparation of this schedule, primary consideration was given to the definition of the flying qualities in terms of factors known to be susceptible of measurement by existing N. A. C. A. instruments or by instruments that could readily be designed and developed. As the N. A. C. A. instruments are not available to all agencies that might be interested in measuring flying qualities, consideration was also given to the possibility of making the measurements with standard aircraft indicating instruments.

As a third step, it was necessary to make tests to demonstrate that the items listed in the tentative schedule could be measured with sufficient precision and that they defined the flying qualities as intended. The flying qualities of the Stinson SR–8E airplane were determined in the fall of 1937. In addition to the actual demonstration of the tests and the test procedure of the tentative schedule, the possibility of using the indicating instruments for obtaining the information required was investigated. The results of the trials with this airplane are reported herein.

The investigation has since been extended to other airplanes. A number of airplanes of various types, of course, will have to be examined before it will be possible to prepare satisfactory quantitative specifications for the flying qualities of airplanes.

INSTRUMENTATION

The items for which measurement is required in order to determine the flying qualities of an airplane and the N. A. C. A. instruments with which these items can be measured are given in table I. The table also includes a list of standard aircraft instruments and other indicating instruments that may be employed in place of the N. A. C. A. instruments.

TABLE I

Items to be measured	N. A. C. A. recording instruments	Indicating instruments
Air speed	Air-speed meter	Air-speed meter.
Time	Timer	Stop watch.
Force to operate the three control surfaces.	Control-force meters	Control-force meters.
Position of the three control surfaces.	Control-position meters	Control-position meters.
Angular motion of the airplane about the three airplane axes.	Turnmeters	Artificial horizon, indicating pitch and roll. Directional gyro or rate-of-turn indicator, indicating yaw.
Normal acceleration	Accelerometer	Accelerometer.
Altitude	Altimeter	Altimeter.
Longitudinal acceleration	Accelerometer	Accelerometer.

All of the basic group of instruments were available at the start of the trials of the Stinson airplane except those needed for the measurement of the forces required to operate the different control surfaces; the existing N. A. C. A. control-force recorders were not adaptable to the particular airplane.

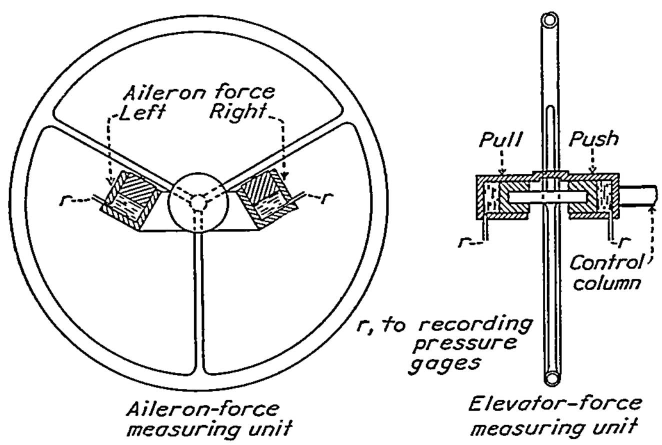


FIGURE 1.—Arrangement of actuating cylinders of wheel-force recorders.

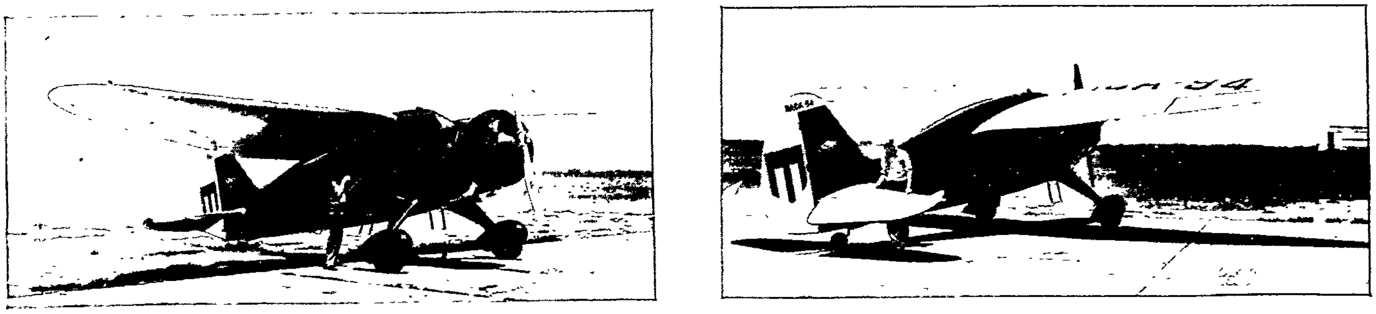
For the measurement of the rudder forces, a brake-pedal-force indicator, developed by the Bendix Company for automobile use, was obtained. It operated hydraulically, the force being applied to a cylinder interposed between the pilot's right foot and the rudder pedal and the reading being given by an indicating pressure gage fitted with a maximum hand. Because of the limited time available for preparation and because the tests were so planned that they required measurement of the maximum force applied and not of the variation of force with time, it was decided to use this instrument as an indicator and not to convert it to a recorder. In the installation of the instrument in the Stinson airplane, the actuating cylinder was mounted on the right rudder pedal so that all maneuvers requiring the measurement of rudder force had to be made to the right.

The instrument developed for measuring the elevator and the aileron forces was constructed according to the same general principles as the rudder-force indicator and involves the use of four actuating cylinders to measure right aileron forces, left aileron forces, elevator push, and elevator pull. The arrangement of these cylinders on the control wheel is shown schematically in figure 1. The instrument was used in conjunction with four recording pressure gages.

Because the altimeter is used for only one measurement, it was decided not to install the recording instrument but to use a sensitive Kollsman indicating altimeter. Where the tests specified the initial conditions for a maneuver, indicating instruments were used for attaining these conditions.

Of the alternate set of instruments, the air-speed meter, the artificial horizon, the directional gyro, and the altimeter normally appear on the instrument panel of a transport airplane. The artificial horizon with the standard dial, however, has no graduations to indicate the angle of pitch. In order to make this instrument suitable for quantitative measurements, the dial must be modified by the addition of graduations of pitch angles in degrees. The indicating accelerometer and the stop watch, although not standard airplane equipment, are readily obtainable. A rudder-force indicator, as already noted, is also available. A wheel-force indicator may be developed along the same lines as the recorder previously mentioned.

In the trial of the indicating instruments on the Stinson airplane, difficulty was expected in connection with the use of the artificial horizon, the directional gyro, and the rate-of-turn indicator. The test program required the measurement of small angular changes, particularly in pitching and yawing, and the measurement of these small values simultaneously at a particular time. A preliminary investigation showed that it was practically impossible, where the motions are rapid, to obtain these readings visually. For the actual tests, therefore, these instruments were especially grouped on the pilot's instrument board along with the stop watch and were photographed with a small motion-picture camera. As no difficulty was anticipated in the use of the wheel-force indicator or in its development from the wheel-force recorder, this instrument was not employed in the tests. For similar reasons, a control-position indicator was not used but, in order to demonstrate that one could be readily made, an instrument was developed and installed in the airplane.



(a) Front. (b) Rear.

FIGURE 2.—Three-quarter views of Stinson airplane.

AIRPLANE

The Stinson airplane used in the investigation is a five-place, externally braced, high-wing, cabin monoplane. It is equipped with partial-span, pneumatically operated, balanced flaps and has a single engine fitted with a two-position controllable propeller. General views are given in figure 2. The specifications of the airplane, as given in the manufacturer's handbook, are included in the following list:

Name and type	Stinson Model SR-8E 5PCLM
Engine	Wright R-760-E2
Rating	320 horsepower at 2,150 rpm
Propeller	Hamilton controllable (two positions)
Fuel capacity	82 gallons
Oil capacity	5 gallons
Gross weight	3,800 pounds
Empty weight	2,417 pounds
Useful load	1,383 pounds
Allowable center-of-gravity limits	22.1 percent to 33.1 percent of mean aerodynamic chord.
Power loading	11.88 pounds per horsepower
Wing loading	14.70 pounds per square foot
Length over-all	28 feet, ¼ inch
Wing span	41 feet, 10½ inches
Height (tail down)	8 feet, 6 inches
Wing chord (tapered)	96 inches maximum
Dihedral	2°
Incidence	2°
Wing area (gross, including flaps and ailerons)	285.5 square feet
Aileron area (both)	22.02 square feet
Flap area (both)	23.82 square feet
Stabilizer area	25.06 square feet
Elevator area (including balance)	19.77 square feet
Fin area	10.8 square feet
Rudder area (including balance)	14.38 square feet

The measured angular deflection of the control surfaces are:

Flap deflection	38°
Aileron deflection	36° up, 23° down
Rudder deflection	±22°
Elevator deflection	±27° (stabilizer tail heavy)
Stabilizer deflection	0° to nose down 9°

The relations between control-wheel position and aileron and elevator position are given in figures 3 and 4. As flown in the tests, the airplane weighed 3,655 pounds and the center of gravity was located at 25.4 percent of the mean aerodynamic chord and 7.2 inches above the thrust axis of the airplane.

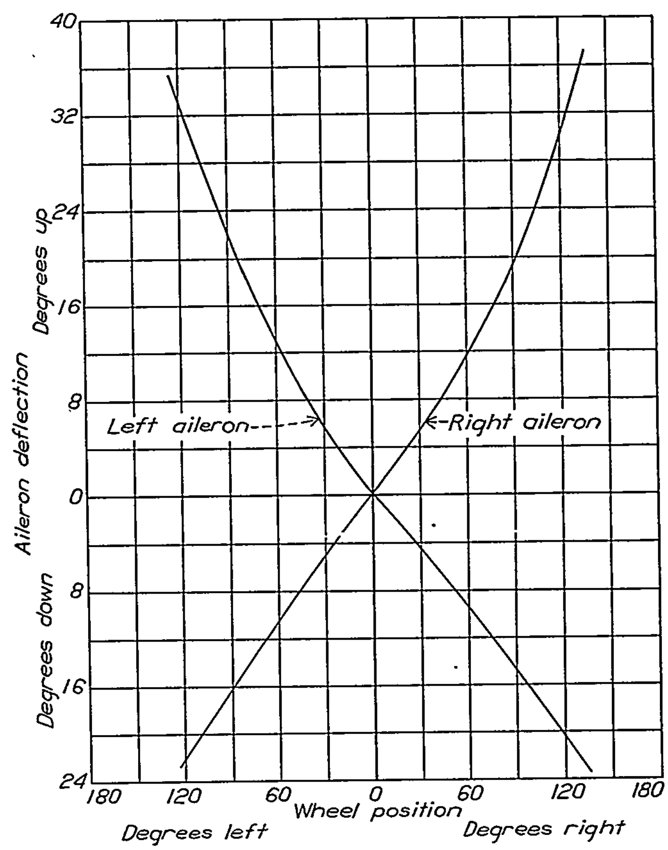


FIGURE 3.—Relation between aileron and control-wheel positions.

The tentative schedule of flying qualities and tests was prepared to include multiengine airplanes equipped with trimming tabs on all three sets of control surfaces. Complete trial was, of course, not possible with the Stinson airplane, which has only one engine and was not fitted with aileron and rudder trimming tabs. For reference, however, the complete tentative schedule has been included in the following presentation of the trials made with the Stinson. The requirements listed are believed to be essential to a completely satisfactory airplane.

Because of the preliminary nature of the trials, variations of propeller pitch and of airplane weight and center-of-gravity position were not tried. All tests were made with the propeller in the high-pitch setting. The weight and the center-of-gravity location for the airplane as flown have already been noted. Two engine conditions were investigated: For the first condition,

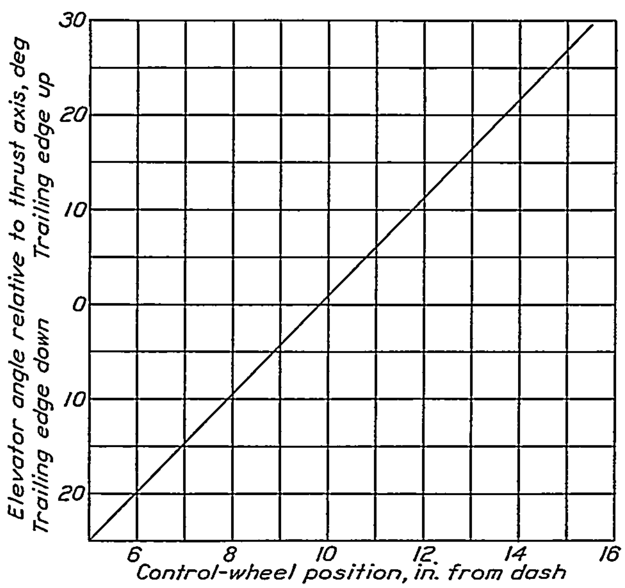


FIGURE 4.—Relation between elevator and control-wheel positions.

the throttle was closed and, for the second, the throttle was set at the position that gave level flight at cruising speed with the flap up. These two throttle settings were used in both the flap-up and the flap-down tests.

LONGITUDINAL-STABILITY AND CONTROL CHARACTERISTICS

LONGITUDINAL STABILITY

Requirement.—With the elevator free, the airplane shall be dynamically stable in pitch at all speeds throughout the speed range. The period of the longitudinal oscillation shall never be less than 40 seconds and the damping shall be sufficient to reduce the amplitude of the oscillation to one-fifth the original amplitude in four cycles.

(Although the numerical limits have been suggested in this and the following requirements, they are, for the most part, considered to be quantitatively unreliable owing to the present lack of data concerning what constitutes satisfactory flying qualities. It is appreciated that, in the final forms for the requirements, airplanes may have to be classified as to purpose and have different numerical values assigned for each category.)

Procedure.—Trim the airplane for the desired speed and then push the stick forward by an amount sufficient to increase the steady speed by 5 to 10 miles per hour. Release the stick and record the variation of air speed with time during the ensuing oscillations as the airplane returns to a steady state at the original trimming speed.

Results and discussion.—As the procedure for the measurement of the period and the damping of the longitudinal oscillation had been employed before, no development was required for the present investigation. With regard to measurements of the damping, however, it may be necessary for precision to vary the speed by more than the 5 or 10 miles per hour suggested in the procedure. The amount depends on the speed range of the airplane being tested and the sensitivity of the recording or the indicating instrument used.

The method of making the measurements by photographing the indicating instruments did not work out as well as expected but it may be further improved. Some difficulty experienced in obtaining sufficient light for photography was overcome by using the fastest commercial film and a relatively fast (f:2) lens. Even with this arrangement, however, no clear pictures were obtained of the stop watch. The stop watch used was unsatisfactory because of the slenderness of the hand, the fineness of the dial markings, and because the face was white with black markings rather than black with white markings. A more suitable watch could probably have been obtained but not within the time available for the tests. Lighting conditions are always likely to be critical where natural illumination is depended upon. For this reason, an additional set of instruments, especially mounted and artificially illuminated for photography, seems to be desirable if the airplane size permits.

The results of the longitudinal-stability measurements are given in figure 5. Figure 5 (a) presents the period of oscillation as a function of speed for the four test conditions. From the figure, the actual periods are noted to be less than the suggested minimum value for all speeds up to 140 miles per hour with either power off or power on. No difference occurs between the flap-up and the flap-down periods for equal speeds. In connection with the disagreement between the actual and the suggested periods, a comparison has been made between the data for the Stinson airplane and the data given in reference 1 for several other airplanes. In this reference, it was observed that the designer has little control over the period of oscillation of a conventional airplane. An empirical formula for the period for the power-off condition, $P=0.262V$, where P is the period in seconds and V is the velocity in miles per hour, was given. The straight line given by this equation has been plotted in figure 5 (a). The agreement between it and the curves for the Stinson airplane indicates that the specification of a constant period is illogical.

The damping characteristics of the longitudinal oscillations are given in figures 5 (b) and 5 (c). Figure 5 (b) presents the measured damping coefficient; and figure 5 (c), the computed number of cycles required for an oscillation to damp to one-fifth amplitude. In figure 5 (c), it should be noted that the actual plot is made of the inverse of the number of oscillations. For most of the speed range for all conditions, the damping is less than the suggested value. For three conditions, the airplane is unstable for portions of the speed range.

The importance of the damping specification is questionable in the light of present knowledge. The Stinson tests and also those reported in reference 1 show that an airplane which, from the pilot's viewpoint, has satisfactory flying qualities may still be dynamically unstable. It is not at all certain that airplanes can be made longitudinally stable under all conditions of flight without adversely affecting some other qualities. Until this point is settled, however, the requirement seems desirable that the airplane be stable in the range wherein the airplane may be flown with the elevator free. The amount of damping is considered of no importance at the present time.

ELEVATOR CONTROL

RANGE OF ELEVATOR CONTROL

Requirement.—The range of the elevator control shall be sufficient to meet the following conditions:

a. With every setting of the trimming device, it shall be possible to maintain steady flight at any speed from the design probable diving speed to the minimum speed for any power condition, flap up.

b. With every setting of the trimming device, it shall be possible to maintain steady flight at any speed from the placarded to the minimum, flap down.

c. With the conventional type of landing gear, it shall be possible to make three-point landings and to hold the tail down while braking enough to give a deceleration of 0.3g during the landing run down to a speed of 30 miles per hour.

d. In the take-off run, it shall be possible to raise the tail off the ground by the time a speed of 30 miles per hour is attained.

e. If a tricycle type of landing gear is used, it shall be possible to raise the nose wheel off the ground in a take-off run by the time a speed of 30 miles per hour is attained. (As has been noted, this and other requirements not relating to the Stinson airplane are included for reference.)

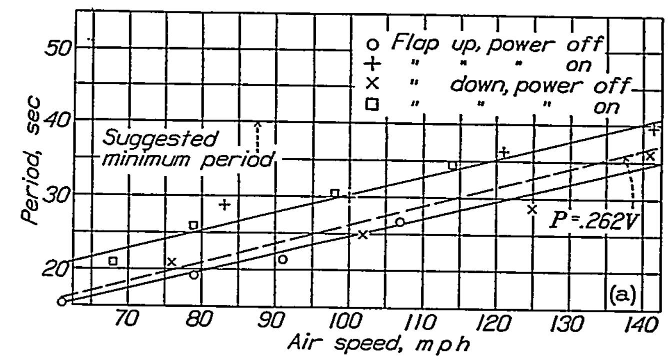
Procedure for items a and b.—Measure the elevator angles at different speeds with different tab or stabilizer settings and different throttle positions.

Procedure for item c.—Merely demonstrate the ability to make three-point landings. For the braking tests, run the airplane along the ground at a speed of approximately 50 miles per hour. Close the throttle and apply brakes to the maximum extent for which the pilot can maintain contact between the tail wheel and the ground. Record the air speed and the longitudinal acceleration as the airplane decelerates to less than 30 miles per hour.

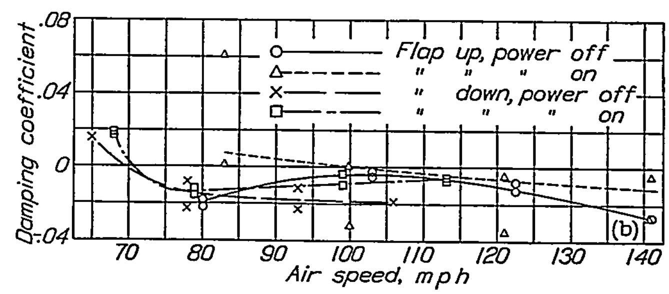
Procedure for item d.—Apply full throttle while holding the airplane with the brakes. Release brakes and attempt to raise the tail as soon as possible. Record speed at which the tail leaves the ground.

Results and discussion.—No difficulty was encountered in carrying out the procedure and obtaining the information desired.

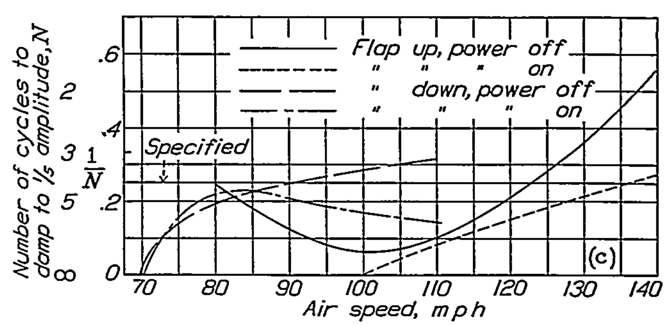
The results of the measurements of the elevator position for steady flight for the Stinson airplane for the four test conditions are presented in figure 6. Although complete measurements were not made for all stabilizer settings δ_s because of high control forces, figure 6 indicates that the range of elevator control should be ample for any desired speed from the minimum up to the high speed in level flight with the flap up. Because of the preliminary nature of the tests, it was considered unwarranted to carry the measurements to the design probable diving speed. With the flap down, the airplane could be flown steadily at any speed from the minimum to the placarded of 125 miles per hour.



(a) Period of oscillation.



(b) Damping coefficient.



(c) Number of cycles to damp to one-fifth amplitude.

FIGURE 5.—Longitudinal-stability characteristics.

The data from the landing tests showed that the airplane could be landed smoothly in a three-point attitude and that the elevator was just sufficient to hold the tail wheel in contact with the ground while braking vigorously enough to give a deceleration of $0.3g$ at 30 miles per hour. The elevator was sufficiently powerful to lift the tail wheel from the ground in a take-off run at a speed so low that precise measurements could not be made.

VARIATION OF ELEVATOR ANGLE WITH SPEED

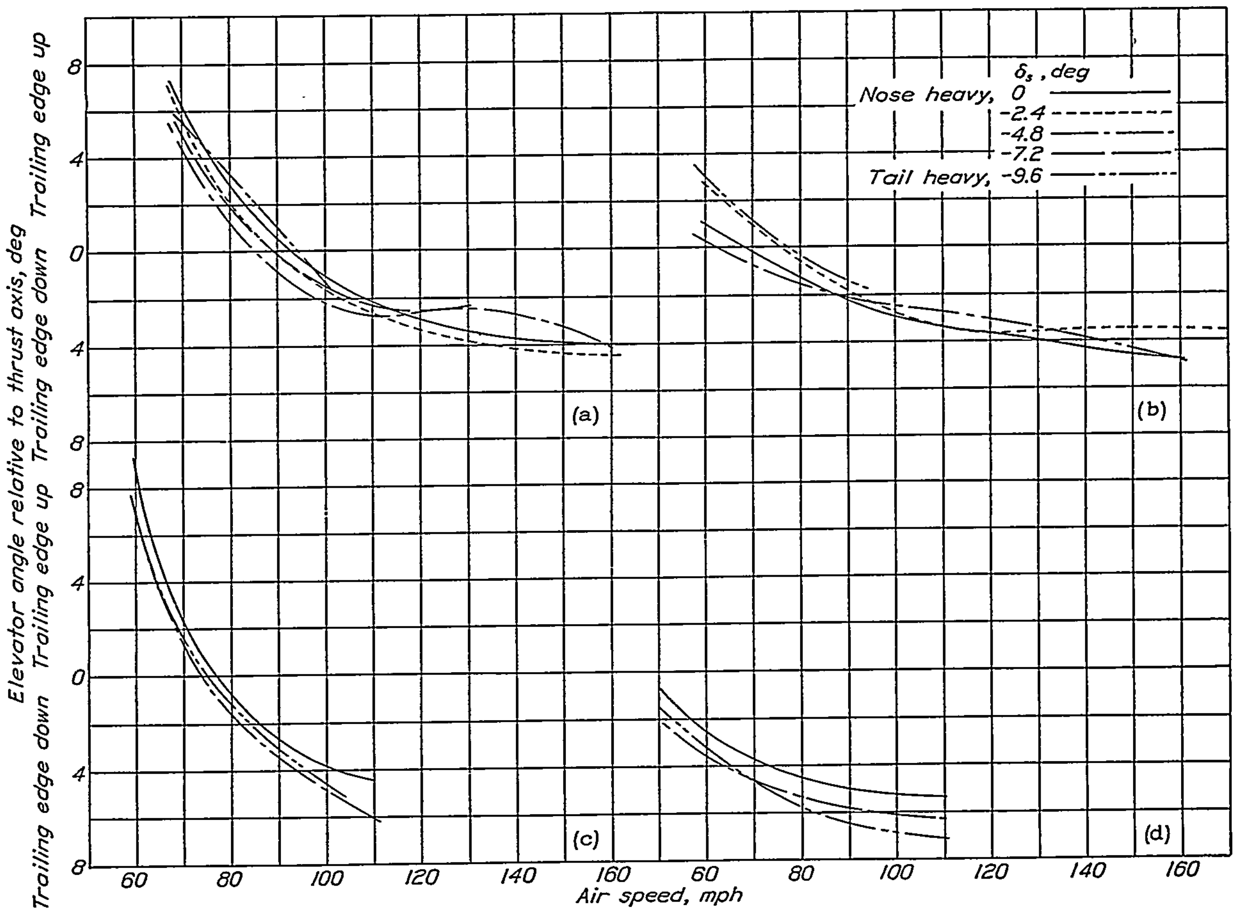
Requirement.—The curve of equilibrium elevator angle against speed for every setting of the trimming tab shall be smooth and shall everywhere within the permissible speed range have a negative slope.

Procedure.—The information needed for this requirement is obtained from the measurements of elevator angle previously discussed under the section Range of Elevator Control.

Results and discussion.—The control-position recorder used for the measurement of elevator angles was, for convenience, connected to the control column in the cockpit rather than to the elevator. The results had to be corrected for the stretching of the elevator cables. In order to make the correction, the amount the elevator deflected relative to the control column per unit applied force was determined by static tests. The constant thus obtained and the recorded elevator-control forces were used to compute the errors in the individual control-position readings.

The actual elevator angles as a function of speed are shown in figure 6. Because the pilot's opinions of stability are influenced by control-column movement, which differs from the elevator movement owing to the cable stretch, figure 7 has also been included presenting the variation of control-wheel position, or apparent elevator angle, with speed.

The curves of figure 6 indicate that, for most of the test conditions and stabilizer settings, the slopes are negative as required. With flaps up and with both power on and power off for certain stabilizer settings, a small range of speeds apparently exists in which the slopes of the curves are slightly positive. The reason for the change of sign of the slopes of the curves for the particular conditions is unknown. The measurements and the corrections were possibly in error by an amount sufficient to produce the positive slopes. Figure 7 indicates that, because of the extension of the control cables, the airplane with the tail-heavy stabilizer settings gave the pilot an impression of



(a) Flap up, power off.

(b) Flap up, power on.

(c) Flap down, power off.

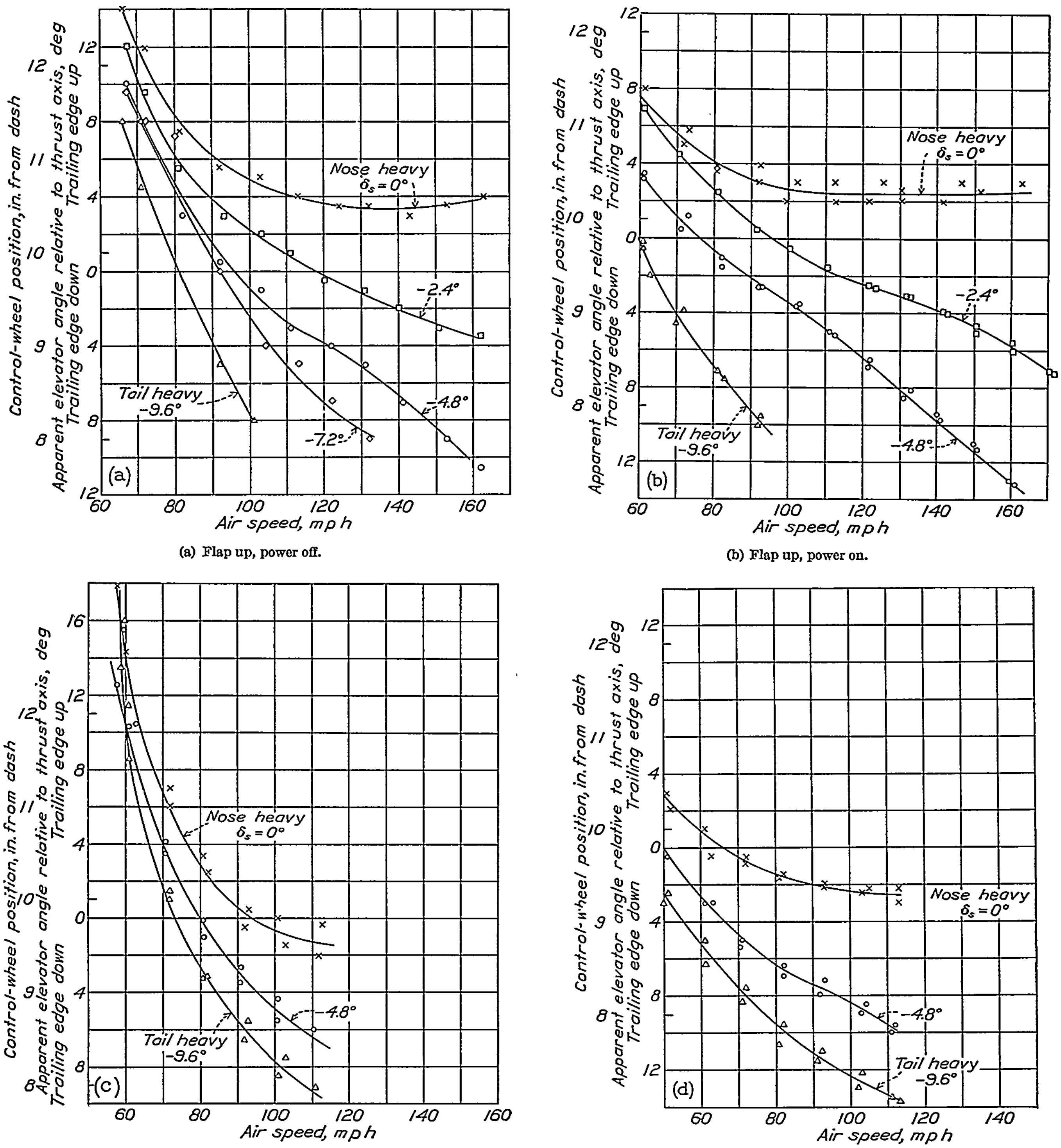
(d) Flap down, power on.

FIGURE 6.—Elevator angles corrected for cable stretch.

greater stability than did the nose-heavy stabilizer settings, although figure 6 shows very little change in the actual elevator curves with stabilizer setting. With the nose-heavy stabilizer setting for the two flap-up conditions, the airplane appeared unstable to the pilot. The comparison between the two sets of curves indicates the need for exercising considerable care in obtaining and interpreting data relating to static longitudinal stability. It is of interest to note that neither half of the elevator travel nor half of the wheel movement was required during the tests.

RANGE OF ELEVATOR-CONTROL FORCE

Requirement.—With every setting of the trimming tabs or the stabilizer, it shall be possible to fly the airplane from the minimum to the maximum permissible speed with a change of elevator-control force no greater than 100 pounds.



(a) Flap up, power off.

(b) Flap up, power on.

(c) Flap down, power off.

(d) Flap down, power on.

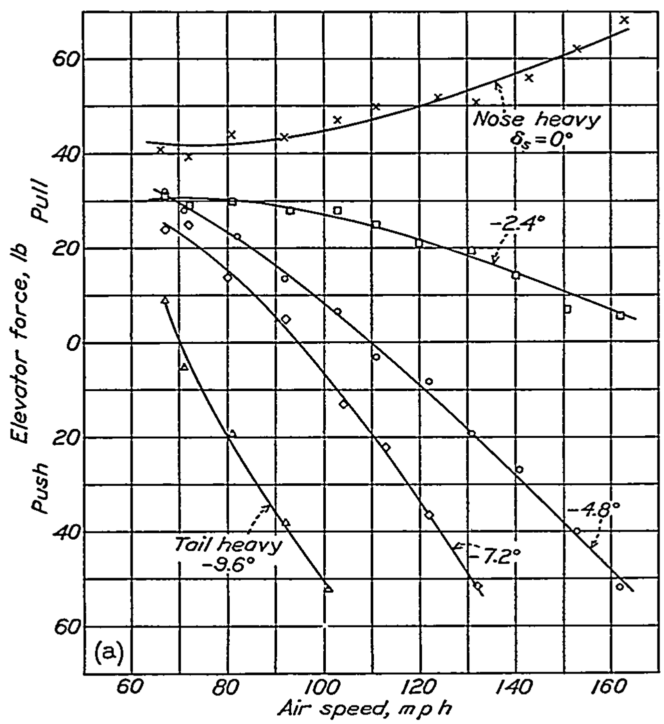
FIGURE 7.—Apparent elevator angles.

Procedure.—Measure the elevator-control force at different speeds with different tab or stabilizer settings and different throttle positions. (These measurements may be made simultaneously with the measurements of elevator angle.)

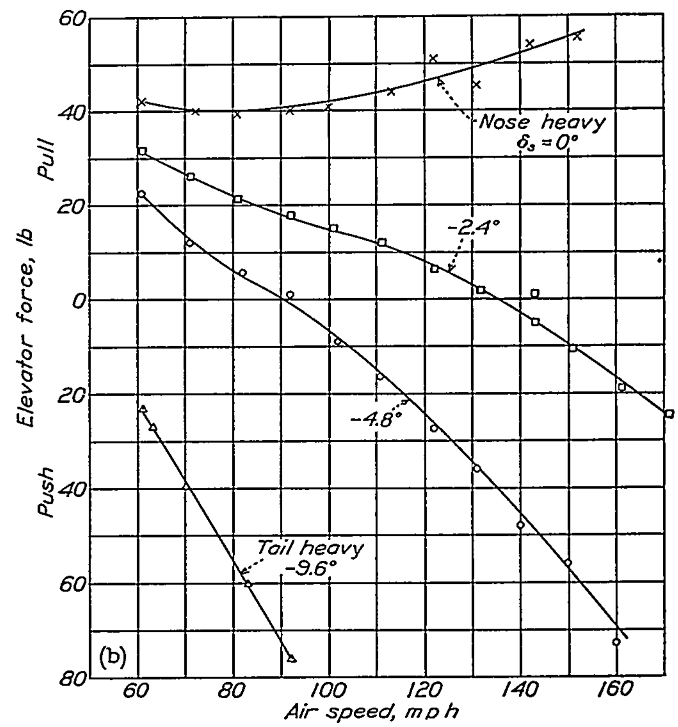
Results and discussion.—The control-force recorder used the first time for these measurements behaved satisfactorily. A slight difficulty was experienced at the start of the investigation because, owing to the arrangement of the electrical system, it was necessary for the pilot to apply the control force with one hand in order to have the other free to operate the instrument switch. With this unsymmetrical application of the load, the actuating pistons would bind and the instrument would give erroneous readings. The trouble was eliminated by arranging for the operation of the instruments by the observer, thus permitting the pilot the use of both hands to apply symmetrical loads.

The results of the measurements of the elevator forces are given in figure 8, which shows that, for the Stinson airplane, the range of the elevator-control forces depends on the stabilizer setting. For the nose-heavy settings, the force variation was small.

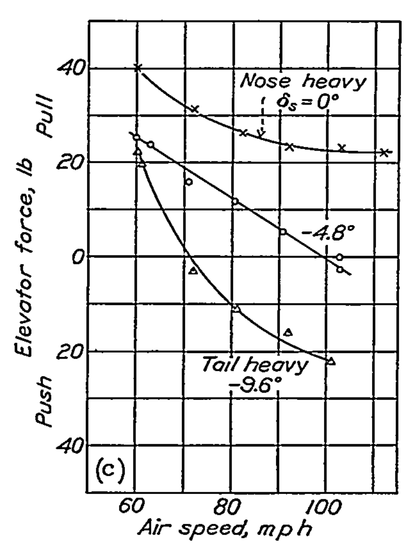
As the airplane was trimmed toward the tail-heavy condition, the range of the elevator forces rapidly increased. This increased variation of force with tail-heavy stabilizer settings is accounted for, in part, by a spring system interconnected with the elevator and



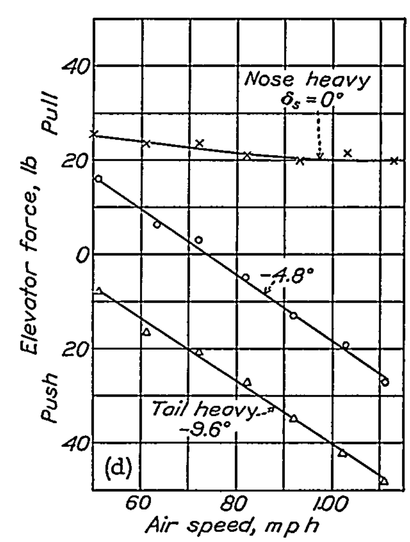
(a) Flap up, power off.



(b) Flap up, power on.



(c) Flap down, power off.



(d) Flap down, power on.

FIGURE 8.—Elevator forces.

trimming control so that, when the stabilizer is set tail heavy, a spring comes into action and increases the force required to pull back on the control column. With the flap down, the suggested range of force was met for all stabilizer settings. With the flap up, although the tests did not cover the complete flight range, it appears that the force variation of less than 100 pounds would not be met with the tail-heavy stabilizer settings, probably because of the spring just discussed.

VARIATION OF ELEVATOR-CONTROL FORCE WITH SPEED

Requirement.—The curves of stick force required for steady flight plotted against the speed of flight for all tab or stabilizer settings shall be smooth without discontinuities or sudden changes of curvature. The slopes shall be everywhere negative throughout the specified speed range and shall nowhere be less than one-fourth pound per mile per hour.

Procedure.—The data relating to this requirement were obtained from the measurements of elevator-control force made in the section Range of Elevator-Control Force.

Results and discussion.—Figure 8 shows that the same nose-heavy stabilizer position that gave an undesirable variation of wheel position (figs. 7 (a) and (b)) also gives an undesirable variation of elevator force. It will be noted, however, that with this stabilizer setting no balance speed exists. The control column must be pulled back throughout the complete speed range. On the basis that the stabilizer range should be insufficient for balance at speeds above the maximum level-flight speed, the results for this stabilizer setting may be neglected in the present discussion. It might be desirable to limit the stabilizer to a setting that would permit trimming at the maximum speed with flap up and power on. In order to make such a decision, however, tests would have to be made with the most tail-heavy positions of center of gravity. With the stabilizer settings that gave balance between the minimum and the maximum speeds, the variation of the elevator-control force with speed was satisfactory.

VARIATION OF ELEVATOR-CONTROL FORCE WITH THROTTLE SETTINGS

Requirement.—The force required on the stick to overcome, without change of tab or stabilizer setting or speed, the effect of any change in the engine operating condition from full power to fully throttled shall not exceed 100 pounds.

Procedure.—The data relating to this requirement are obtained from the measurements of elevator-control force made in the section Range of Elevator-Control Force.

Results and discussion.—The effect of opening the throttle is to make the airplane trim more tail heavy. The change of force required to maintain a given speed when the throttle is varied from the closed to the power-on condition varies from 0 to 40 pounds, depending on the speed and on the settings of the flap and the stabilizer.

RANGE OF STABILIZER OR ELEVATOR TRIMMING TABS

Requirement.—

a. It shall be possible to trim the airplane at a low enough speed so that no greater force than the 30-pound pull would be required in performing a three-point landing.

b. It shall be possible to trim the airplane at its maximum level-flight speed.

Procedure for item a.—Measure the maximum elevator force in a landing with the stabilizer or the trimming tab set full tail heavy.

Procedure for item b.—The data relating to this requirement were obtained from the measurement of elevator-control force made in the section Range of Elevator-Control Force.

Results and discussion.—The range of the stabilizer is greater than required with the airplane as loaded for the tests. No force measurements were made in the actual landings but, with flap down and power off, the landing condition, the airplane could be stalled with a pull of the order of 25 pounds with the stabilizer in the tail-heavy position. As previously noted, the airplane may be trimmed with the stabilizer at speeds above the maximum.

EFFECTIVENESS OF ELEVATOR CONTROL

Requirement.—

a. As an indication of the effectiveness of the elevator for maneuvering the airplane, it shall be possible to obtain an acceleration of 0.8 of the design applied load factor at any speed with the elevator alone and with the airplane originally trimmed for cruising speed, when a force of not more than 200 pounds and not less than 60 pounds is applied to the control wheel.

b. At low speeds down to 10 miles per hour above the minimum where the theoretical maximum acceleration approaches 1, it shall be possible to change the attitude of the airplane in space with respect to its transverse axis in either direction by 5° in 1½ seconds by use of the elevator alone.

Procedure for item a.—Trim the airplane for cruising speed. Increase speed to the design probable diving speed. Make pull-up to 0.8 of the applied load factor, using an indicating accelerometer for reference. Record acceleration, speed, and stick force. Repeat at various speeds throughout the speed range.

Procedure for item b.—Trim the airplane for a speed 20 miles above the minimum. Apply full-up elevator and record angular velocity and air speed. Repeat, applying full-down elevator. Repeat at various speeds to the minimum.

Results and discussion.—The tests to determine the effectiveness of the elevator for maneuvering were made in the manner outlined with no difficulty as far as the procedure and the operation of the recording instruments were concerned. No measurements were

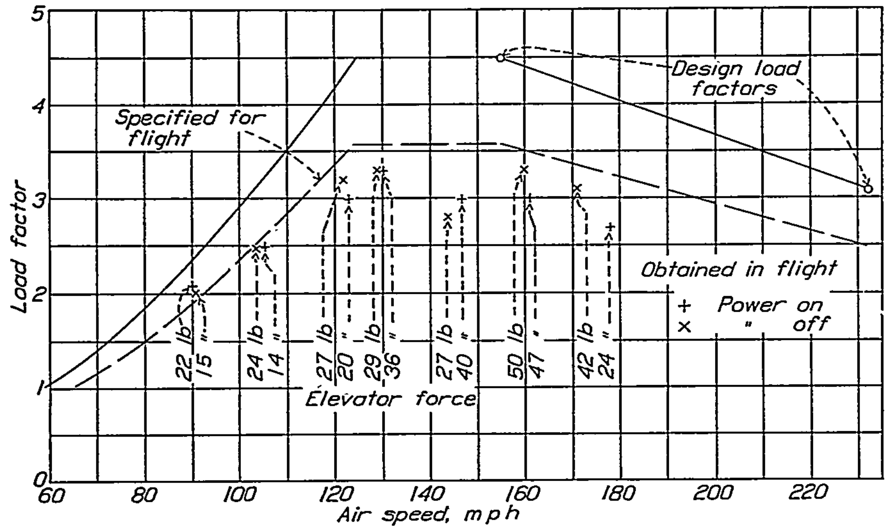


FIGURE 9.—Elevator forces required to obtain normal accelerations at various speeds.

made at speeds greater than the maximum for level flight. In the trial of the indicating instruments, the camera had to be rigidly mounted. This rigid mounting may occasion a little difficulty in small airplanes, although it was readily accomplished with the Stinson. An inspection of the photographs made showed that the indicating accelerometer and the artificial horizon with the modified dial were suitable for the measurements. The photographs were not evaluated because of the previously mentioned trouble with the photographs of the stop watch.

The results of the measurements are given in figures 9 and 10 and in the following table. Figure 9 shows the forces required to obtain an acceleration of approximately 0.8 of the applied load factor at various speeds when the airplane is trimmed for cruising speed. The results show that, within the range of the tests, the forces fell well below the upper limit of 200 pounds and they all were, in fact, below the minimum limit. The requirements need some revision. The force probably should be defined as a function of speed and the values of 200 and 60 pounds made to apply at some definite speed.

Figure 10 shows the manner in which the attitude of the airplane can be changed in pitch at low speed with the elevator alone. The figure has been prepared for only the flap-up power-off condition. The lengths of time to rotate the airplane through angles of 5° and 10° in pitch given by figure 10 are listed in table II. Similar data are also given for the other three test conditions.

TABLE II

Test condition	Speed (mph)	5°		10°	
		Pull-up (sec)	Push-down (sec)	Pull-up (sec)	Push-down (sec)
Flap up, power off	71	0.51	0.44	0.81	0.72
	77	.46	.46	.64	.71
	81	.39	.46	.59	.73
	86	.38	.46	.53	------
Flap up, power on	66	.56	.46	------	.73
	70	.49	.48	.69	.71
	77	.43	.39	.58	.57
	80	.40	.39	.72	.54
	86	.45	.45	.67	.63
Flap down, power off	60	.50	.51	.82	.75
	65	.51	.47	.79	.71
	70	.48	.50	.66	.72
Flap down, power on	60	.46	.49	.66	.78
	65	.42	.54	.62	.84
	70	.43	.38	.60	.58

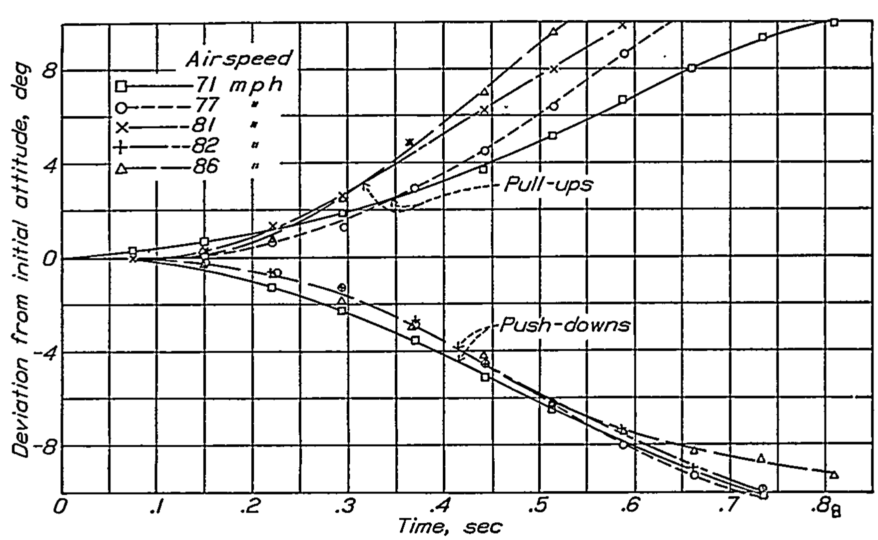


FIGURE 10.—Variation of attitude with time following abrupt elevator deflections at low speeds. Flap up, power off.

The values given in table II do not represent ultimate conditions. The pilot made the maneuvers only as abrupt as he thought necessary to meet the requirement. Even then, the values of time obtained for a 5° change of attitude were in the order of one-third of the 1½ seconds specified.

LATERAL STABILITY AND CONTROL CHARACTERISTICS

LATERAL STABILITY

Requirement.—

a. The airplane shall be laterally stable for the same conditions for which longitudinal stability is required. The period of the lateral oscillations shall not be less than 20 seconds and the damping shall be sufficient to reduce the amplitude of the oscillation to one-half the original amplitude in two cycles.

b. Between the minimum trimming speed and the minimum speed, the airplane shall show no negative dihedral effect nor any autorotative tendencies.

c. From the minimum speed to the limit of the elevator control, there shall be no sudden development of marked autorotative tendencies nor any sudden change in lateral stability characteristics.

Procedure for item a.—Trim the airplane about all three axes for flight at the desired speed. Start a lateral oscillation by rolling the airplane with the ailerons, by yawing the airplane with the rudder, or by placing the airplane in a sideslip through the combined use of the rudder and ailerons. Free the controls and record the ensuing angular motion in yawing and pitching and the air speed. Because of unsymmetrical rigging and power effects, these tests should be made to both sides.

Procedure for items b and c.—Obtain information by direct observation of low-speed and stalled-flight characteristics. A sample copy of the data sheet used for the Stinson airplane is given in table III.

TABLE III

FORM USED FOR OBSERVATIONS OF LOW-SPEED AND STALLING CHARACTERISTICS

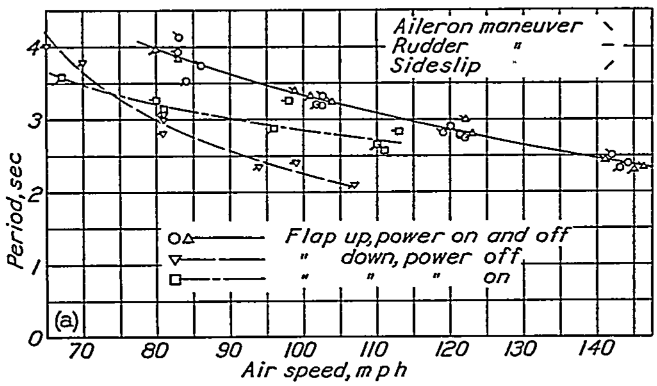
Flap up, power off:

1. Can normal turns with 15° bank be made within 5 miles per hour of stall?
2. As speed is decreased to stall, will airplane bank normally with rudder movements?
3. Do ailerons lose effectiveness progressively?
4. Is there any tendency for airplane to fall off and spin before minimum speed is reached?
5. Is stall progressive or sudden and violent?
6. Beyond the stall, what is relative effectiveness of rudder and ailerons?
7. With stick hard back, can airplane be flown reasonably steadily for 10 seconds?
8. Is tail buffeting violent?

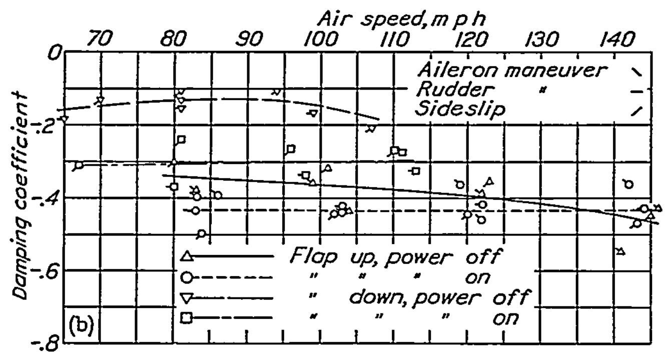
Results and discussion.—It will be noted in requirement a that no differentiation is made between the different types of control-induced disturbances. This procedure is in accordance with the theory which predicts that the ultimate motion is independent of the type of disturbance. Because of the usual procedure in the past of differentiating between the lateral and the spiral motion, some uncertainty was felt regarding this conclusion from the theory. With the Stinson, therefore, the three types of disturbances given under the procedure were tested. The requirement also presupposed that the airplane could be laterally balanced at any speed through the use of aileron and rudder tabs. As the Stinson airplane was not fitted with these additional controls, three series of aileron maneuvers were made. In the first series, all controls were freed after the airplane attained a bank angle of 15°; in the second series, the ailerons were returned to neutral and held there during the ensuing motion; and, in the third series, the ailerons were freed but the rudder was held neutral.

The test procedure given for item a was satisfactorily employed for the tests. Visual observations had to be made of the spiral motion. The recorded yawing velocity was used as the basic parameter for the computations of the characteristics of the lateral oscillations. With regard to the indicating instruments, the movement of the indicator on the directional gyro was found to be too small for the angular displacements involved in the oscillation to permit obtaining quantitative data. It is believed that, if the dial of the rate-of-turn indicator were graduated for angular velocity, this instrument could be used for the measurements. Computations of the period of oscillation made from the data for this instrument gave fair agreement with the results obtained from the recording instruments.

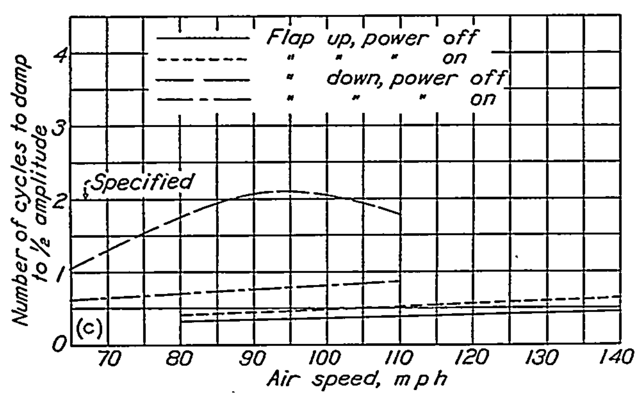
The tests showed that the Stinson airplane was laterally unstable with the flap up below speeds of 140 miles per hour. With the flap down, it was unstable at the highest test speed, 110 miles per hour. This instability took the form of a spiral divergence, as was determined from observations and not from the instrument records. In connection with the spiral characteristics of the airplane, it was noted that the ultimate motion of the airplane depended upon the amount of bank obtained before the controls were freed. For both aileron rolls and sideslips, the initial angle of bank was greater than 10°. For these maneuvers, the consequent spiral tightened up somewhat when the controls were freed before an ultimate steady condition was attained. In the abrupt rudder kicks, the first motion was primarily yawing. Only a small amount of roll occurred in the first second. If the rudder was freed before the airplane had time to bank appreciably, the spiral motion was imperceptible so that, when the lateral oscillation damped out, the airplane remained in sensibly straight flight. When the rudder deflection was held long enough for the airplane to attain an angle of bank equivalent to that obtained in the aileron maneuvers, the airplane behaved approximately the same as in the aileron tests. The results of the measurements of the lateral oscillation are given in figure 11. Figure 11 (a) shows the period of oscillation; figure 11 (b), the damping coefficient; and figure 11 (c), the number of cycles to damp to one-half amplitude. It



(a) Period of oscillation.



(b) Damping coefficient.



(c) Number of cycles to damp to one-half amplitude.

FIGURE 11.—Lateral-stability characteristics.

will be noted from these figures that the characteristics of the lateral oscillation were independent of the type of maneuver used to set up the disturbance. In all cases and at all speeds, the period is below the suggested minimum of 20 seconds. The damping, except for a 15-mile-per-hour range with flap down and power off, is greater than suggested.

From the results of this investigation, the conclusion is drawn that the complete information on lateral-stability characteristics can be obtained from any of the three maneuvers so that in the future the performance of the other two will be unnecessary. It is suggested that the aileron maneuvers, which are the least violent of the three, be used for the purpose.

No difference was noted in the lateral-stability characteristics when the ailerons were held neutral instead of being free. Presumably the control friction was so small that the ailerons returned to neutral of their own accord. With the rudder held neutral, the increase of the effective fin area was indicated by slight changes in the speed at which the airplane became stable and in the period of the lateral oscillation.

The observations made for items b and c showed that the airplane had no negative dihedral effect at any point in the flying range to the limit of the elevator travel. Autorotative tendencies were noted at and beyond the stall in straight flight. Stall could be induced 3 to 4 miles per hour above the minimum speed by abrupt full use of the ailerons. The stall was progressive and not particularly violent.

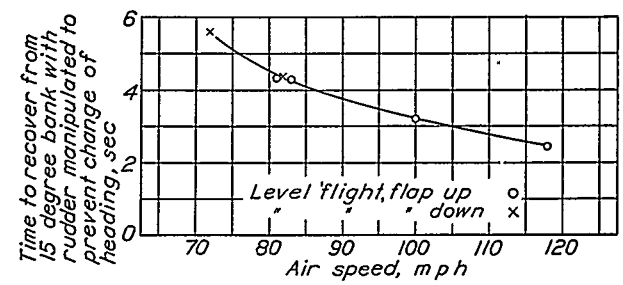


FIGURE 12.—Dihedral effect; recovery from a 15° bank through the action of roll due to sideslip.

LIMITS FOR ROLL DUE TO SIDESLIP (DIHEDRAL EFFECT)

Requirement.—

a. The dihedral effect shall be sufficient that, when the ailerons are freed immediately after putting the airplane in a 15° bank and using the rudder to avoid a change of heading, the angle of bank shall be reduced to 2° within 15 seconds and with a loss of altitude of not over 300 feet.

b. The rolling acceleration accompanying abrupt rudder displacement shall be less than one-half the yawing acceleration.

Procedure for item a.—Place the airplane in a steady sideslip with one wing down 15°. Release the ailerons and record the rolling motion of the airplane and the altitude lost in recovery to straight flight.

Procedure for item b.—In the steady-flight condition, apply full rudder abruptly and record the resultant yawing and rolling motion.

Results and discussion.—The tests regarding the minimum dihedral effect, item a, were made with no particular difficulty except that, at low speeds, the rudder was insufficient to prevent the airplane from yawing in a 15° bank. Inspection of the photographs of the indicating instruments showed that the artificial horizon could probably be used for the measurements, but no evaluation was made because of the poor photographs of the stop watch. The data obtained from the recording instruments are presented in figure 12. The figure shows that the airplane has an appreciably greater dihedral effect than required, the maximum time recorded for the recovery being only 5½ seconds as against the 15 seconds specified. The loss of altitude during the recovery for the power-on condition was negligible. For the power-off condition, no apparent increase occurred in the vertical velocity during recovery.

The tests to determine the maximum dihedral effect, item b, were unsatisfactory because of the violence of the maneuver. The measurements were made in connection with the rudder tests and the results will be discussed later in the section dealing with the rudder controls.

AILERON CONTROL

AILERON POWER

Requirement.—

a. At a speed of 70 miles per hour with the flaps down and 80 miles per hour with the flaps up, it shall be possible to bank the airplane 15° in 2½ seconds with the ailerons alone and, at 120 miles per hour or higher, the same angle of bank shall be obtained in 2 seconds.

b. At a speed 2 miles per hour above the stall with the flaps down, it shall be possible to bank the airplane 10° in 2 seconds with the ailerons alone.

c. The aileron effectiveness shall be proportional to the aileron deflection.

Procedure.—At the specified speeds, apply full aileron control and record rolling velocity and aileron position. Repeat with ⅘, ⅗, ⅖, and ⅕ aileron deflection.

Results and discussion.—The procedure and the recording instruments had been used in previous aileron tests and, as expected, were satisfactory for the purposes of the present investigation. The artificial horizon in conjunction with a suitable stop watch appeared to be a satisfactory indicating instrument for obtaining the desired information.

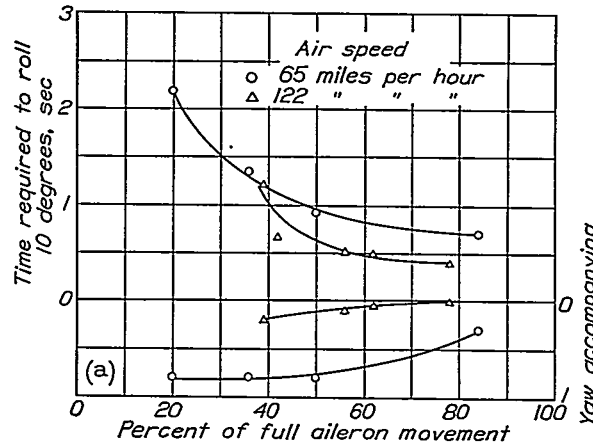
The results of the measurements are given in figures 13 to 15. Figure 13 gives the time for the airplane to roll 10° at two speeds with the flap up and at two speeds with the flap down. No reason being apparent for changing angles between items a and b of the requirements, figure 13 was prepared on the basis of a single arbitrarily chosen angle. The speeds for the tests were not in strict accordance with those of the requirements. Figure 13 shows that Stinson ailerons will meet the conditions suggested in item a of the requirements. Tests were not made at a speed of 2 miles per hour above the stall with the flaps down because observations had shown that the airplane could be stalled at that speed by abrupt use of the ailerons.

Figures 14 and 15 present the data on aileron power in terms of the maximum rolling acceleration and the maximum rolling velocity. These figures show that, although the aileron effectiveness is not in direct proportion to the deflection, the variation with deflection is smooth and progressive.

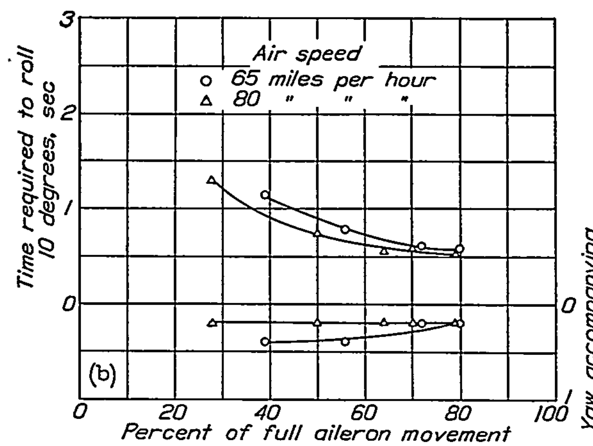
AILERON FORCES

Requirement.—

a. The force required to attain the aileron reactions listed under the section Aileron Power shall not exceed 50 pounds applied tangentially at the rim of the wheel.



(a) Flap up, power off.



(b) Flap down, power off.

FIGURE 13.—Time to roll 10° with ailerons.

b. The aileron force shall be approximately proportional to the aileron deflection.

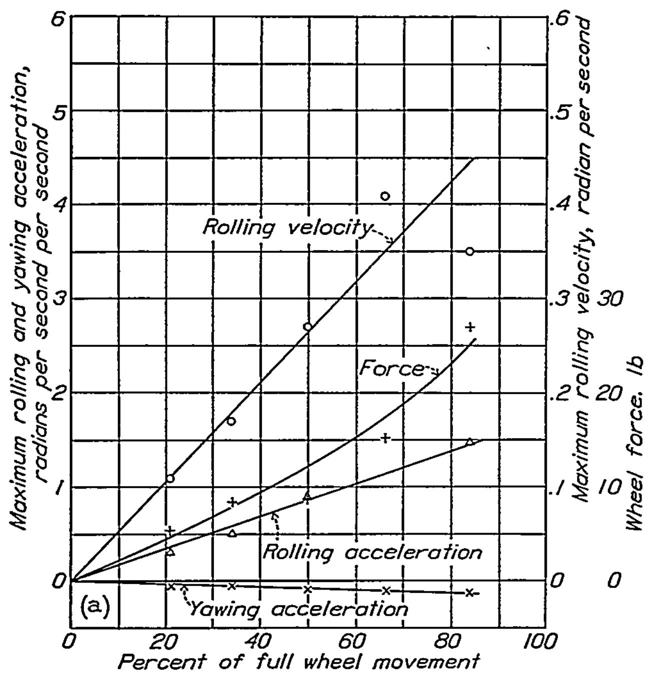
Procedure.—The information relating to these requirements may be obtained by supplementing the procedure listed in the section Aileron Power with measurements of aileron forces.

Results and discussion.—The data have been plotted in figures 13 to 15. For the highest test speed, the figures show that 40 pounds were required for full deflection of the ailerons. At all speeds, the aileron forces varied somewhat in proportion to the aileron deflection. Although the variation was not strictly linear, the curve was smooth and showed no abrupt changes in slope.

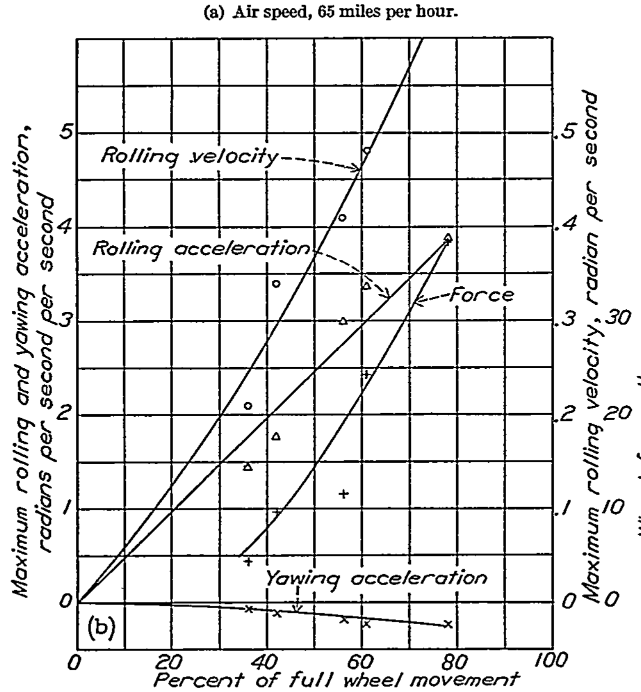
YAW DUE TO AILERONS

Requirement.—At speeds beyond 10 percent more than the minimum speed, the ailerons shall not produce a yawing acceleration greater than one-tenth the acceleration in roll. At speeds below 10 percent more than the minimum, the acceleration in yaw shall be less than one-fifth the acceleration in roll.

Procedure.—The information relating to this requirement may be obtained by supplementing the procedure listed in the section Aileron Power with measurements of angular motion of yaw.



(a) Air speed, 65 miles per hour.



(b) Air speed, 122 miles per hour.

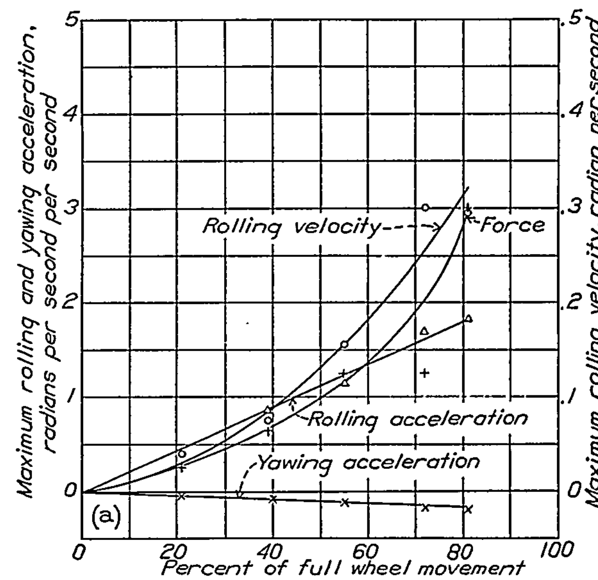
FIGURE 14.—Aileron characteristics. Flap up, power off.

Results and discussion.—The information obtained has been plotted in figures 13 to 15. For no condition was the yawing acceleration caused by the aileron as great as one-tenth of the rolling acceleration. Similarly, the airplane did not yaw 1° in the time taken to obtain a bank of 10°.

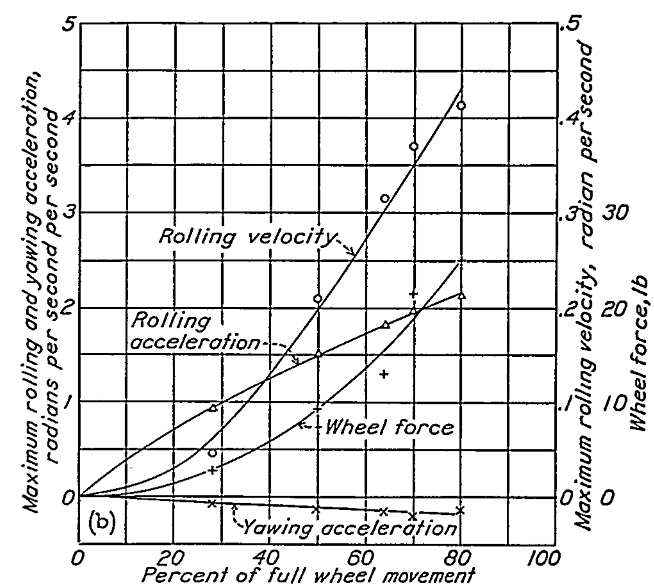
AILERON TRIMMING TABS (NOT APPLICABLE TO STINSON)

Requirement.—

a. It shall be possible by the use of the aileron tabs to balance the airplane against the dissymmetry in loading corresponding to full gas tanks on one side of the center of gravity and empty gas tanks on the other.



(a) Air speed, 65 miles per hour.



(b) Air speed, 80 miles per hour.

FIGURE 15.—Aileron characteristics. Flap down, power off.

b. It shall be possible by the use of the aileron tabs to compensate for any rolling tendency accompanying steady flight with asymmetrical power conditions.

RUDDER CONTROL

RUDDER POWER

Requirement.—

a. It shall be possible during steady flight at 70 miles per hour with the flaps down and 80 miles per hour with the flaps up to produce a change of heading of 15° in 3 seconds by the use of the rudder alone. At and beyond 120 miles per hour, the same change shall be possible in 2 seconds.

b. At 2 miles per hour above the stall with the flaps down, it shall be possible to make flat turns up to a change of heading of 10° in 2 seconds.

c. At 20 miles per hour above the minimum speed, as well as at any higher speed, it shall be possible to hold a straight course with the wings laterally level with both engines on either side cut out and with those on the other side operating at full rated power.

d. With any three engines operating or with one outboard and the opposite inboard one cut out, it shall be possible to hold a straight course on the ground down to 50 miles per hour with the flaps either up or down.

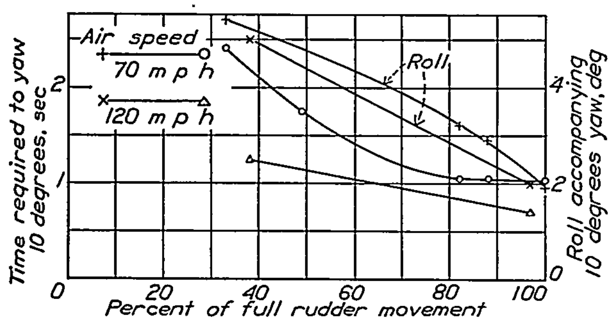


FIGURE 16.—Time to yaw 10° with rudder. Flap up, power off.

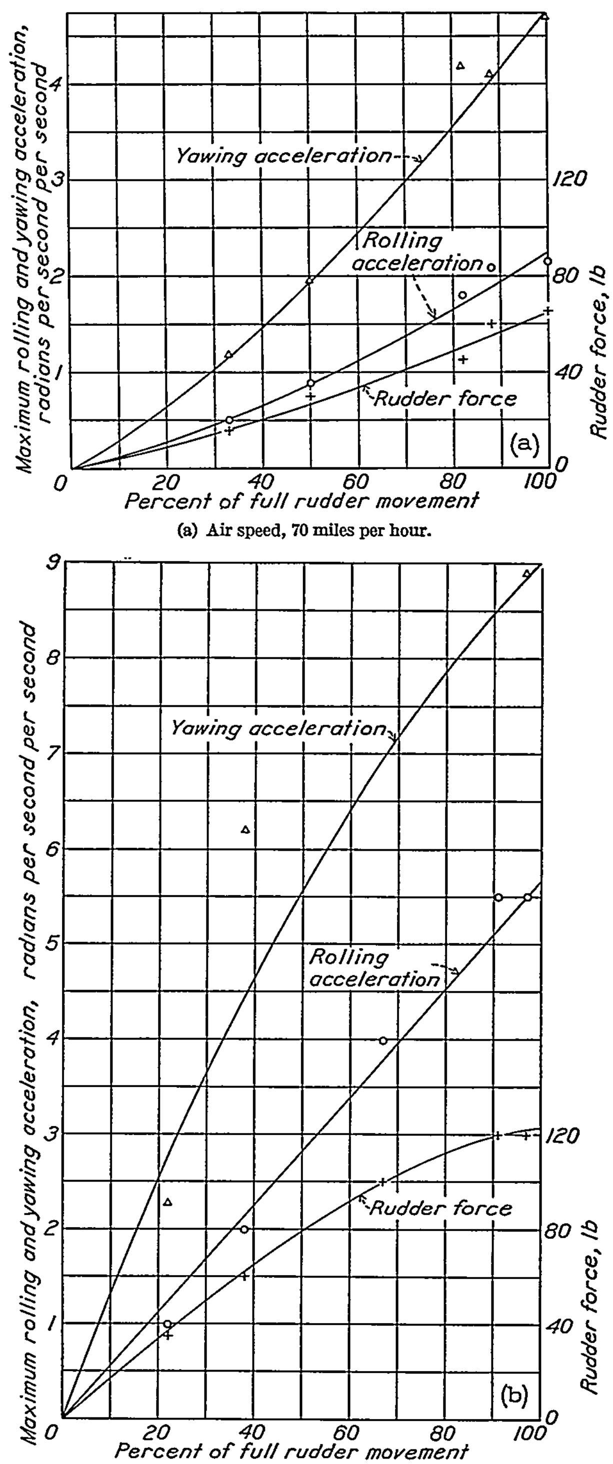
(Items c and d are not applicable to the Stinson.)

e. The rudder effectiveness shall be proportional to the rudder deflection.

Procedure for items a and b.—Trim the airplane laterally and longitudinally at the desired speed. Apply abrupt full rudder control. Record rudder position and rolling and yawing velocities. Repeat with ⅘, ⅗, ⅖, and ⅕ rudder deflection. This procedure is similar to that for item b for Dihedral Effect.

Results and discussion.—Insofar as the recording instruments were concerned, these tests were made satisfactorily. The actual maneuvers, however, were very violent and the requirements should preferably be rewritten to eliminate the need for fully deflecting the rudder. Because of the violence of the maneuvers, the tests were not made with the flaps down. The results of the tests for the flap-up condition are given in figures 16 and 17. The manner of presentation is similar to that for the aileron data.

The data of the figures, although not conclusive because they do not include the flap-down condition, indicate that the rudder is considerably more powerful than necessary to meet the requirements as written. The specifications, in addition to requiring more violent maneuvers than are considered necessary, are believed not to define the maximum rudder power that may be desired. It is therefore suggested that the primary requirement for rudder power be based on the maximum angle of bank which can be held in the steady sideslip. The present requirement may be treated in a subsidiary manner similar to the requirement regarding the ability to change altitude with the elevator.



(a) Air speed, 70 miles per hour.

(b) Air speed, 120 miles per hour.

FIGURE 17.—Rudder characteristics. Flap up, power off.

Figure 17 shows that the rolling acceleration resulting from an abrupt rudder kick is of the order of one-half the yawing acceleration. This fact indicates that the effective dihedral is at the upper limit permitted by the requirements for dihedral. If the rudder specification is changed, the specification for the maximum dihedral should also be revised. It is suggested that the dihedral be defined in terms of the amount of aileron required to hold the specified angle of bank in a steady sideslip.

RUDDER FORCES

Requirement.—

a. It shall be possible to obtain the rudder reactions without applying a force greater than 180 pounds to the rudder pedals.

b. The rudder force shall be proportional to the rudder deflection.

Procedure.—The data may be obtained by supplementing the tests of the previous section by measurements of rudder force.

Results and discussion.—The data for rudder force have been plotted in figures 17 and 18. The maximum force recorded was 120 pounds. At both test speeds, the rudder force varied almost linearly with rudder deflection.

RUDDER TRIMMING TABS (NOT APPLICABLE TO STINSON)

Requirement.—

a. Down to 10 percent in excess of the minimum speed, it shall be possible, by adjustment of the trimming tabs, to fly straight with any three engines operating or with one inboard and the opposite outboard engines cut out with no force on the rudder pedals.

b. Down to 20 miles per hour above the minimum speed, flaps down, it shall be possible with the trimming tabs to reduce to 30 pounds the force on the rudder pedals required for straight flight with both engines on either side cut out and with those on the opposite side operating at full rated power.

COMBINED OPERATION OF RUDDER AND AILERONS

EFFECTIVENESS FOR MANEUVERING

Requirement.—

a. It shall be possible to enter a 45° banked turn at 140 miles per hour in 5 seconds without having the rudder force exceed 100 pounds or the aileron force exceed 75 pounds. The same limitations on forces shall apply to a 30° banked turn at 200 miles per hour entered in 4 seconds.

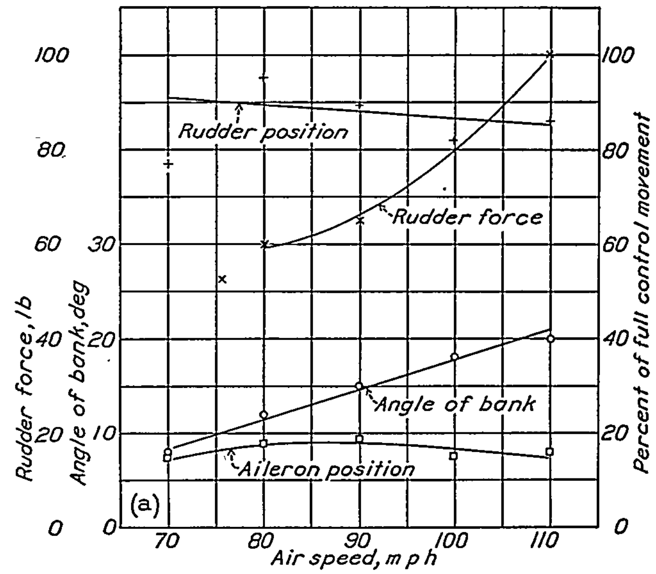
b. It shall be possible to make normal banked turns up to a 15° bank at speeds within 5 miles per hour of the minimum with the flaps either up or down. It shall be possible with flaps either up or down to fly the airplane steadily for at least 10 seconds up to the limit of the elevator control if the elevator control is sufficient to stall the airplane.

c. It shall be possible, at speeds beyond 10 percent more than the minimum, to maintain a steady sideslip with an angle of bank of 20°.

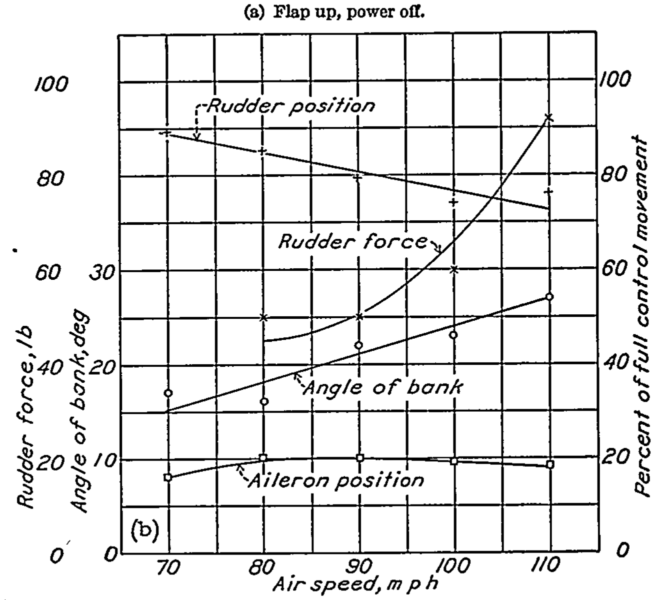
Procedure for item a.—At the specified speeds, make the required turns using the artificial horizon for reference and measure the maximum rudder and aileron forces.

Procedure for item b.—Obtain the desired information by direct observation.

Procedure for item c.—At a series of speeds beyond 10 percent more than the minimum, place the airplane at the maximum steady sideslip that can be maintained. Obtain the angle of bank from the artificial horizon. Record the speed and the rudder and the aileron positions and the rudder and the aileron forces.



(a) Flap up, power off.



(b) Flap up, power on.

FIGURE 18.—Sideslipping characteristics.

Results and discussion.—The results of the measurement of the forces in normal turns are given in table IV. In no case do the forces approach those specified.

TABLE IV

Flap	Speed (mph)	Maximum bank (deg)	Entry time (sec)	Maximum forces (lb)			
				Elevator	Ailerons Right	Ailerons Left	Rudder
Up	81	45	6	16	7	4	------
Do	137	50	5	38	10	10	40
Down	78	60	6	31	9	11	35
Do	122	60	6	35	10	8	40

From direct observation, it was found possible to make banked turns with a 15° angle of bank down to a speed of 5 miles per hour more than the minimum for all conditions. With power off, the airplane handled normally down to the stalling speeds. With power on at about 3 miles per hour above the stalling speed, an uncontrollable lateral oscillation of constant amplitude was encountered. At the stall with power on, this oscillation became unstable and the airplane consistently fell off to the left. With power off, the airplane could be controlled indefinitely beyond the stall to the limit of the elevator control. The flight was not very steady however, because any movement disturbed equilibrium conditions.

The results of the sideslip tests are given in figure 18, which is indicative of the type of data that will be obtained if the rudder and the dihedral specifications are changed. It will be noted that, in the sideslip, approximately 20 percent of the full aileron control was used and practically the entire rudder deflection was required. With power off, only at the highest speed could the specified angle of bank of 20° be maintained.

CONCLUDING REMARKS

The results of the tests of the Stinson airplane have indicated that the tentative schedule of flying qualities and flight tests is generally satisfactory. The following revisions are suggested:

(a) The specification for the period of the longitudinal oscillation should be changed so as to define the period on the basis of the empirical equation

$$P=0.262\ V$$

where P is the period in seconds and V is the air speed in miles per hour. The period is permitted to deviate from the value given by this equation with the power off ± 5 seconds and with the power on ± 10 seconds.

(b) The specification relating to the amount of damping should be eliminated. If this omission seems inadvisable, the amount of damping should be based on the number of cycles for the oscillation to decrease to one-half amplitude instead of to one-fifth amplitude.

(c) The specification for the maximum amount of effective dihedral should be based on the amount of aileron control required to obtain a specified amount of bank in the steady sideslip.

(d) The rudder specification should be based on the maximum angle of bank that can be held in the steady sideslip with full rudder control. The present specification relating to the change of heading in 1 second should be made subsidiary.

The recording instruments used for the measurements functioned satisfactorily. The control-force recorder, however, is cumbersome and difficult to install because of the four high-pressure rubber tubes required to connect the recorder to the indicator. In order to improve the situation regarding this instrument, the decision has been made to convert it to an indicator by installing four indicating pressure gages directly on the wheel. Thus, in future investigations, a recording air-speed meter, an accelerometer, two turnmeters, and a control-position recorder will be used in conjunction with a wheel-force indicator, a rudder-force indicator, and an indicating altimeter. The further use of the complete set of indicating instruments by the Committee is considered inadvisable.

The possibility of using only indicating instruments has been demonstrated and refinements have been indicated. The refinements should include an improvement to the arrangements for photographing the instruments, probably through the use of an extra set especially mounted and artificially illuminated, and should include modification and the calibration of the rate-of-turn indicator.

The tests of the Stinson airplane involved approximately 20 hours of flying time. About one-fourth of this time may be attributed to repeat flights resulting from improper operation of the control-force recorder, which was developed and tried for the first time during these tests. On the basis of the experience obtained, it is estimated that similar tests with one center-of-gravity position could be repeated on another airplane with a total flying time of approximately 10 hours. The over-all time would depend on the weather conditions but, with ordinary weather, it is estimated that tests could be completed in 2 weeks. This estimate refers to tests with one propeller pitch setting and one center-of-gravity location. A change of propeller pitch is expected to have little effect on the flying qualities and check tests at different pitch settings would add little flying time. The center-of-gravity changes permitted on most large airplanes are so great as to require a complete repetition of the test program; the total time required would therefore depend on the number of center-of-gravity positions tested. Probably only the rearmost and the foremost positions would have to be tested, in which case it appears that not more than 4 weeks would be required.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *March 29, 1940.*

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1. Soulé, Hartley A.: Flight Measurements of the Dynamic Longitudinal Stability of Several Airplanes and a Correlation of the Measurements with Pilots' Observations of Handling Characteristics. Rep. No. 578, N. A. C. A., 1936.